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A Fresh Look at Cogeneration

More competitive energy markets, advancing generation technology, and innovative financing tools create new opportunities for combined heat and power

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This electroplating company in Ontario uses a natural-gas fueled cogeneration system to supply hot water for the electroplating process.

Cogeneration, also called combined heat and power (CHP) or total energy, has developed into an economical mainstream choice for effective energy conversion, overall emissions reduction, and positive returns on investment. Despite its many proven benefits, CHP remains a misunderstood technology.

In reality, the classical CHP application—around the clock operation, with large, continuous heat loads—still applies for some heat intensive applications. In many distributed generation applications, this notion of long-hour CHP applications no longer applies.

Several factors combine to create more opportunities for CHP than existed even a few years ago.

Electricity markets have become more competitive, creating incentives for businesses to take control of their energy costs by installing on-site power generation. In such settings, effective heat recovery from generating equipment can improve the return on investment significantly while displacing air emissions from boilers or other means of creating heat.

Market conditions favor distributed generation as a way for utilities to add capacity to power grids quickly and cost effectively. Many of these small-scale power systems are installed in facilities that offer economic opportunities for heat recovery—even if the generating equipment operates only 2000 to 3000 hours per year.

Technological advances in natural-gas-fueled reciprocating engine generating systems have driven down both the installed first cost of equipment and the long-term cost to generate electricity.

Innovative financing programs free companies from investing their own limited capital in CHP systems and can enable positive cash flow starting within the first year of operation.

In general, engine-driven generator sets can produce heat well suited to a variety of needs: space heating, domestic or industrial water heating, absorption cooling, desiccant dehumidification, and light industrial process loads such as in dairy farming, baking, cooking, and pharmaceutical production. A CHP system does not need to serve such loads year-round or for 24 hours per day to be cost effective—nor does a facility heat load have to be large enough to use all the heat that can be recovered from the engine.

European businesses have embraced CHP for years (albeit with help from government subsi-

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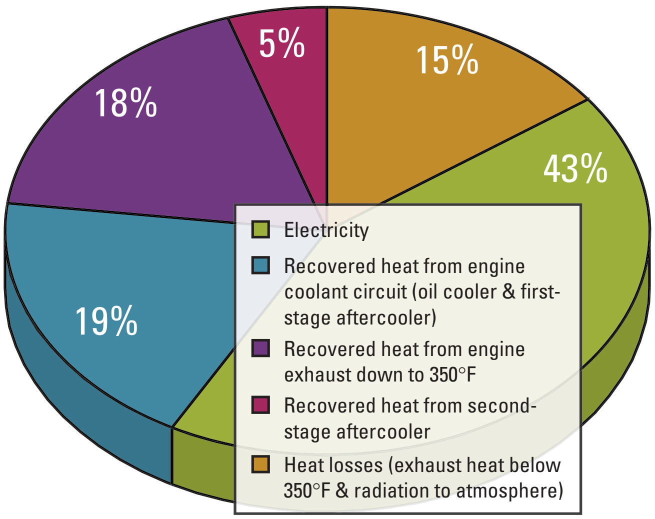

Figure 1. The pie chart illustrates the relative size of the potential sources of heat recovery in a CHP system using a gas engine-driven generator set. In this example, about 15% of the fuel's energy is lost, which means the CHP system is 85% efficient. A specific CHP system's efficiency depends on many factors, including the mechanical efficiency of the generator set, the thermal load required, and the nature of the heat recovery equipment.

dies and integrated government policies) for its capacity to reduce fuel consumption and limit air-pollutant emissions.

Beyond Stereotypes

Several common stereotypes about CHP tend to confuse and discourage potential users. For example, prevailing beliefs hold that CHP economics work only:

- In facilities with large, continuous process heat loads and with generating equipment that operates at full load, around the clock
- In limited geographic areas with high electric rates and low fuel prices
- With large generating equipment that uses complex and expensive heat-recovery systems

However, the realities of CHP are far different. To make a heat-recovery application cost effective and to be considered CHP, a system does not have to extract all available heat from a generating source, nor does it have to operate continuously. Furthermore, the heat recovery technology can be very simple. An automobile heater is a simple CHP application.

Simple applications also can work in industry. For example, at an open pit mine in Idaho, an equipment workshop relied on a 250-kilowatt (kW) generator set to produce its power. In summer, the radiator blew air to the outside, but in winter, workers diverted air warmed by the radiator into the building by moving a section of plywood from one position to another.

Such rudimentary devices will not deliver major economic benefits, but they do demonstrate that the only absolute requirement to make CHP feasible is that the value of heat recovered at an application outweighs the incremental cost of the heat-recovery mechanism.

Changing Markets

Changes in the electricity markets now work in favor of natural-gas-fueled CHP. As the uncertain path of electric industry deregulation continues to affect the power market, growing numbers of customers see economic advantages in having capacity to generate at least a portion of their own electricity. In fact, many electric utilities now encourage utility-dispatched distributed generation as a means to build new capacity faster, at lower cost and less risk than for building large, centralized power plants.

Generation capacity installed near the point of use also helps utilities avoid the costs and siting problems involved in building new transmission and distribution lines. It has the added advantage of helping to maintain voltage stability on local distribution systems, thus delivering the power quality today's electricity users demand. Customer-owned gas-fueled distributed generation systems can take various forms, including:

- Continuous power systems that give the owner complete control over power reliability and quality

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- Standby power systems sized to sustain critical production loads
- Peak shaving (customer-load shaving) or peak sharing (utility coincidental peaking shaving) systems
- Hybrid cooling systems that enable switching between natural gas and electricity

Trigeneration is a growing form of CHP technology in which heat energy from the generator set is captured for either heating or cooling. In an application commonly found in commercial buildings, some of the heated water or steam from the generator set can be diverted to an absorption chiller or desiccant dehumidifier to help meet seasonal space-conditioning needs.

Any applications that entail 1000 or more annual operating hours have potential for CHP, as long as the owner can cost-effectively use the recovered heat.

Today's Generators

Modern gas-fueled generator set technologies lend themselves well to extended-duty distributed generation service. Using advanced engineering designs, reciprocating engine generator set manufacturers have driven down the per-kilowatt first-installed cost of equipment by extracting higher power density from essentially the same engine block. Meanwhile, advances like digital electronic engine controls have increased fuel economy, reduced maintenance costs, and tightened control over emissions, thus simplifying compliance with air-quality regulations.

Today's natural-gas-fueled generator sets can achieve simple cycle mechanical efficiencies up to 43% without heat recovery, versus 32 to 37% just a few years ago. With the addition of CHP systems, heat recovery can dramatically improve overall system efficiency and positively influence return on investment.

Total CHP system efficiency up to 95% is technically possible; system efficiencies from 75 to 85% are achievable at reasonable cost (see figure 1).

Keeping It Simple

The latest gas-fueled reciprocating engine generating technologies magnify the potential for cost-effective, intermittent-duty CHP systems. The classic model of

CHP includes heat recovery first from the jacket water, oil cooler, and first-stage aftercooler circuit, then from engine exhaust. (Some systems also extract heat from the aftercooler's second stage.). CHP users must remember that the primary purpose of a heat recovery system is to reject heat from the engine. Any CHP system that does not allow for adequate engine cooling under all expected heat and electric loads is headed for rapid and costly failure.

Heat recovery from the engine cooling circuit is extremely simple: A low-cost shell-and-tube heat exchanger can produce hot water at temperatures from 180° to 225°F, depending on the jacket water temperature of the engine. Production of potable hot water requires a dual-heat recovery circuit to isolate engine coolant from the heat load. While the dual-heat recovery circuit is slightly more expensive than the single-pass shell and tube-heat exchangers, it can still create a cost-effective source of high quality hot water.

Exhaust heat-recovery systems come at higher engineering, equipment, and operating costs, and are usually not cost-effective unless the CHP system will serve a large and consistent heat load. Exhaust heat recovery in today's lean-burn, low-emission engines is limited by relatively low engine exhaust temperatures for production of hot water or lower-quality steam (typically 15 to 20 pounds per square inch [psi]). Such engines are technically capable of producing higher-quality steam (up to 125 psi), but in volumes too small to be meaningful in most applications.

The need to recover exhaust heat must be balanced carefully against the need to keep the exhaust gas temperature above the point where water vapor (the most common by-product of combustion) and unburned hydrocarbons will precipitate out of the exhaust flow and collect in the exhaust system. Uncontrolled wet stacking, or "slobbering" creates maintenance issues and potential safety concerns. If it is economically feasible, there are techniques used today to capture the condensed water from the exhaust.

> Any CHP project must compete for capital with other business priorities.

In addition, exhaust heat-recovery systems are inherently more expensive because they operate at higher temperatures and pressures, thus requiring more costly materials and advanced safety controls. For these reasons, economics generally dictate longer annual service hours to cost-justify exhaust heat recovery systems.

Intermittent Applications

Simple jacket-water heat-recovery systems (see figure 2) lend themselves well to limited-duty CHP systems of the kind made feasible by growth in distributed generation.

Office buildings in many areas can cost-effectively operate generator sets five days per week during business hours, avoiding utilities' highest time-of-use rates. If the owner can self-generate at five cents per kilowatt-hour, versus purchasing energy at seven or eight cents per kilowatt-hour at utility prices, then the on-site generator itself provides an attractive return. If heat recovery from an inexpensive jacket-water heat exchanger can partially or fully offset the cost of fuel for space heating, water heating, or dehumidification, then return on investment improves.

A small or mid-sized manufacturer with an on-site generator set and a hot-water load amounting to roughly one-third of the heat recoverable from the engine cooling circuit could use a heat exchanger installed in the engine's cooling system loop, with a thermostatically controlled diverter valve to regulate the flow to the in-plant load, to cost-effectively satisfy the hot-water requirement.

Other applications for heat recovery from on-site generation include domestic hot water, laundries, kitchens, or swimming pool heaters in hotels and food processing applications.

The Financing Side

Prospective CHP owners set different financial "hurdle rates" by which to judge investments in energy-saving projects. To evaluate the economics realistically, owners should first conduct a cost-benefit analysis to decide what forms of heat recovery and operating scheme will deliver the most attractive return. In many cases, a continuous-duty system with jacket water and exhaust heat recovery may not provide the best return. The key questions to ask are whether the system's main purpose is to provide electricity or heat, and which will provide the greatest economic return

More Information

- Visit the Department of Energy's Building Cooling Heat and Power site at www.bchp.org/index.html
- The U.S. Combined Heat and Power Association (USCHPA) site at www.nemw.org/uschpa

Any CHP project must also compete for capital with the prospective owner's other business priorities. Many organizations measure "hurdle rates" in terms of simple economic payback. Large businesses with high product turnover tend to have aggressive payback expectations—from several months to two years. Businesses that produce durable goods may find longer paybacks of two to four years to be acceptable. Government agencies and institutions (such as schools or hospitals) may accept payback in three to five years, or longer.

Today's financing vehicles provide alternatives to return on investment calculations based on

Figure 2.The main components of a natural-gas fueled cogeneration system.

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simple payback alone. For example, traditional debt financing or leases can be structured with fixed monthly or annual payments, costing less than the owner's net savings on energy. In this scenario, the owner sees immediate positive cash flow—a net reduction in operating expenses from the first month in service. Leased equipment has the added advantage of being classified as an operating expense rather than capital expense. This classification can help expedite management approvals and take the projects out of competition for capital.

The Time Has Come

In 1995, the U.S. Combined Heat and Power Association (USCHPA) estimated that CHP provided about 44 gigawatts of the nation's generating capacity, about 6% of the total. In 1998, the U.S. Department of Energy (DOE) issued the CHP Challenge, calling on industry and government to work together to double the nation's CHP to about 92 gigawatts by 2010 (see figure 3).

The USCHPA accepted the challenge. Working with the DOE and the U.S. Environmental Protection Agency, the association produced a National CHP Roadmap that outlines an ambitious plan to add 46 gigawatts of new CHP capacity by the end of the current decade.

Meanwhile, work continues on new, more efficient reciprocating engine technologies. The U.S. Department of Energy's Advanced Reciprocating Engine Systems (ARES) program aims to develop cleaner, more efficient gaseous-fueled engines, largely for the distributed generation and CHP markets. The DOE and major engine manufacturers support ARES, which, over the next several years, will produce a new generation of highly advanced gas engines that use improved materials, new fuel handling and processing systems, and enhanced ignition, and combustion systems.

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Technical innovation and market developments continue that make CHP ever more viable continue to arrive. Only more imagination and education delay its long-awaited arrival as a commonplace solution. ***eun***

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United States Industrial Sector 2001 Baseload CHP Technical Market Potential

NAICS Group	Engine Size Range (MW)						
	0.5-1*	1-2	2-5	5-6.5	6.5-10	10-20	Total
Agriculture (dairy)**	943	na	na	na	na	na	943
Mining	690	686	806	176	431	634	3,423
Construction	-	-	-	-	-	-	-
Food	976	2,650	2,032	1,197	706	998	8,559
Beverage and Tobacco	132	313	377	74	118	99	1,113
Textile Mills	194	490	1,028	288	360	264	2,623
Textile Products	154	125	114	15	24	15	448
Apparel	273	233	167	20	30	16	739
Leather	47	44	33	5	9	-	137
Wood Product	742	1,099	664	74	73	(55)***	2,597
Paper	635	1,213	2,633	435	851	1,019	6,785
Printing	195	133	77	18	-	-	422
Petroleum	216	285	707	114	214	771	2,307
Chemical	1,762	1,417	3,272	1,217	1,723	2,691	12,082
Plastics and Rubber	1,170	1,616	1,472	287	307	394	5,246
Nonmetallic Minerals	472	336	616	116	265	76	1,881
Primary Metals	385	450	1,832	752	1,469	2,500	7,387
Fabricated Metals	1,159	1,067	902	53	115	81	3,377
Machinery	410	339	375	47	99	129	1,399
Computer and Electronics	1,315	1,394	2,032	401	933	2,521	8,597
Electrical Equipment	334	594	856	168	175	381	2,509
Transportation Equipment	549	925	1,496	430	451	4,091	7,941
Furniture	377	321	236	47	72	57	1,110
Miscellaneous Manufacturing	197	204	170	23	59	5	658
Total	**13,324**	**15,934**	**21,897**	**5,957**	**8,484**	**16,687**	**82,283**

* The values could be overestimated due to lack of data on existing on-site generation capacity for facilities with less than 1-megawatt capacity.
** Includes load for dairy farms only. The estimate reflects the steam load requirements (in MW) of dairy farms. Dairy farms require far more steam than electricity, and the load (in MW) reflects the required load to satisfy their steam needs. Due to lack of data, no disaggregation by engine size category is offered..
*** The negative value indicates that the estimated power load requirement is smaller than the existing on-site (mostly CHP) capacity. This is not a surprising outcome since CHP units could be sized to satisfy the plant's steam load, which could require a much larger size than if sized according to electric load.

Figure 3. The table represents the technical market potential for CHP in the industrial sector in the United States in 2001.The industrial sector offers the largest CHP opportunity among the three end-use sectors (the others being commercial and residential) due to the large thermal requirements. Information courtesy of ARES Market Study, EEA Inc.